MODIS TEB electronic crosstalk correction update and impact on L1B product uncertainty

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Abstract

The MODIS instruments onboard the Terra and Aqua satellites have been in operation for over 22 and 20 years, respectively. The instruments' calibration accuracy has been maintained, even with instrument degradation. Electronic crosstalk in the thermal emissive bands (TEB) is a known issue with an increasing impact on the calibration and product. The Terra MODIS photovoltaic (PV) longwave infrared (LWIR) bands crosstalk corrections have been applied in Collection 6.1 (C6.1). However, the electronic crosstalk contamination for some detectors in the mid-wave infrared (MWIR) bands and the Aqua PV LWIR bands affect the Level-1B (L1B) product's measurement accuracy and image quality. In Collection 7 (C7), crosstalk corrections for select detectors in the Terra and Aqua MWIR and Aqua PV LWIR bands are applied. The entire mission crosstalk coefficients for the select detectors and bands are derived from scheduled lunar observations and populated in the form of look-up tables (LUTs). The Aqua PV-LWIR bands exhibit similar downward crosstalk trends as the Terra PV-LWIR bands, especially in recent years. The crosstalk coefficients and their trends provide a guideline for the correction application. Earth measurement analyses before and after the correction provide contamination and correction assessments. It has been shown that the product quality is enhanced with the crosstalk correction applied in C7. For C7, the crosstalk coefficient uncertainty is derived from the fit residuals between the measured values and a linear fit over a three-year sliding window. The uncertainty propagation is modeled and applied in the total uncertainty calculation in the L1B product. The TEB electronic crosstalk LUTs have been processed over the entire Terra and Aqua MODIS missions. This paper presents the C7 crosstalk correction, as well as its assessment and uncertainty propagation algorithm to the TEB uncertainty.

Keywords: MODIS, radiometric calibration, TEB, crosstalk, uncertainty

1. INTRODUCTION

The Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) instruments have successfully operated for 22 and 20 years, respectively. Terra is in a morning orbit (10:30 am local equator crossing time; descending southward) and Aqua is in a complimentary afternoon orbit (1:30 pm local equator crossing time, ascending northward). Many science products have been continuously generated from MODIS observations in support of the remote sensing community and users worldwide for their studies of the Earth's geophysical properties and their changes over different spatial and temporal scales[1-9]. MODIS is a scanning radiometer that uses a two-sided scan mirror and collects data in 36 spectral bands with wavelengths covering the visible (VIS), mid-wave infrared (MWIR), and long-wave infrared (LWIR) spectra at three nadir spatial resolutions - 0.25 km (bands 1-2), 0.5 km (bands 3-7), and 1 km (bands 8-36). Sixteen of the MODIS spectral bands (bands 20-25 and 27-36) are referred to as the thermal emissive bands (TEB). These cover wavelengths from 3.75 to 14.24 µm. Observations from the MODIS TEB support a number of science data products, such as surface/cloud/atmospheric temperatures, could top altitude, and water vapor properties. Table 1 lists the MODIS TEB characteristics, including their specified center wavelengths (CW), bandwidths (BW), typical scene temperatures (T_{TYP}), noise equivalent temperature difference (NEdT), and their primary applications.

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For the TEB, the blackbody (BB), along with lunar observations and Earth-view (EV) measurements, are used for post-launch calibration. The MODIS TEB on-orbit calibration, performed with an on-board BB and a space view (SV), uses a quadratic response function. The nonlinear calibration coefficients are characterized on-orbit with quarterly-scheduled BB warm-up and cool-down (WUCD) events. During the WUCD, the BB temperature varies from 270 K to 315 K. The instrument's non-linear coefficient and offset terms are updated (as needed) in the form of look-up tables (LUT) for the Level-1B (L1B) product. Electronic crosstalk, identified during preflight characterization, has shown increased effects on orbit, primarily on the image quality and radiometric stability[10-13]. In particular, the electronic crosstalk effects increased substantially for MODIS post the Terra safe mode event in 2016 and Aqua safe mode in 2022. The calibration improvements are necessary to maintain the MODIS L1B data accuracy and image quality.

In this paper, we present calibration algorithm improvements for the Collection 7 (C7) L1B product with a focus on the electronic crosstalk corrections and their associated uncertainty assessments. Section 2 provides the MODIS instrument calibration, crosstalk, and calibration algorithm improvements. Section 3 focuses on the crosstalk coefficients trending and the crosstalk correction assessments using EV imagery. Section 4 presents the uncertainty associated with the crosstalk.

Table 1. MODIS TEB characteristics and primary applications (CW: center wavelengths; BW: bandwidths, T_{TYP}: typical temperatures, NEdT: noise equivalent temperature difference)

TEB Band	CW (μm)	BW (μm)	T_{TYP} (K)	NEdT (K)	Primary Use
20	3.75	0.18	300	0.05	Surface/cloud temperature
21	3.96	0.06	335	0.20	
22	3.96	0.06	300	0.07	
23	4.05	0.06	300	0.07	
24	4.47	0.07	250	0.25	Atmospheric temperature
25	4.52	0.07	275	0.25	
27	6.72	0.36	240	0.25	Water vapor
28	7.33	0.30	250	0.25	
29	8.55	0.30	300	0.05	Cloud properties
30	9.73	0.30	250	0.25	Ozone
31	11.03	0.50	300	0.05	Surface/cloud temperature
32	12.02	0.50	300	0.05	
33	13.34	0.30	260	0.25	Cloud top altitude
34	13.64	0.30	250	0.25	
35	13.94	0.30	240	0.25	
36	14.24	0.30	220	0.35	

2. BACKGROUND

2.1 MODIS TEB calibration algorithm

The MODIS TEB include the MWIR bands 20-25, covering a wavelength range from 3.8 to 4.5 μm, and LWIR bands 27-36, from 6.8 to 14.2 μm. The TEB detectors are located on two cold focal plane assemblies (CFPAs): a short-wave and mid-wave infrared (SMIR) FPA and a LWIR FPA. The two CFPAs are nominally controlled on-orbit at 83K using a passive radiative cooler and a heater. The on-board BB serves as the primary calibration source, while the SV provides a reference for instrument background. Normally, the BB temperature is set to

290 K and 285 K for Terra and Aqua MODIS, respectively. Starting April 2020, the Terra BB temperature setpoint was changed to 285 K to be closer to the typical temperature for TEB in general and for consistency with Aqua MODIS. The MODIS TEB calibration uses a quadratic calibration algorithm on a scan-by-scan basis for each TEB detector and scan-mirror side. The linear gain coefficient of the response function is calibrated scan-by-scan using a two-point calibration performed via the response to the on-board BB referenced to the SV, and the non-linear and offset terms coming from an offline LUT that is updated periodically. The BB WUCD operation is used to characterize and update the instrument non-linear response coefficients on-orbit. Every WUCD operation is performed quarterly, and the BB temperature varies from instrument ambient temperature (about 270 K) to 315 K. The calibration radiance (L_{CAL}) from the BB view is defined as[14]:

$$L_{CAL} = RVS_{BB}\varepsilon_{BB}L_{BB} + (RVS_{SV} - RVS_{BB})L_{SM} + RVS_{BB}(1-\varepsilon_{BB})\varepsilon_{cav}L_{cav}, \quad (1)$$

where ε is the BB or cavity (cav) emissivity, L is the radiance for the BB, scan mirror (SM), or cavity, and RVS is the response-versus-scan-angle at the SV or BB view. The TEB calibration is based on a quadratic algorithm that converts the digital response of the sensor to calibration radiance (L_{CAL}):

$$L_{CAL} = a_0 + b_1 dn_{BB} + a_2 dn_{BB}^2, \quad (2)$$

where a_0 and a_2 are the offset and non-linear coefficients, and dn_{BB} is the BB's digital response. Equations (1) and (2) are used for both the WUCD and scan-by-scan linear coefficient calibrations during nominal operation. The scan-by-scan linear coefficient, b_1, can be calculated using the emissivity, RVS, and nonlinear coefficients LUTs:

$$b_1 = [L_{CAL} - a_0 - a_2 dn_{BB}^2]/dn_{BB}. \quad (3)$$

Using the calibration coefficients for each detector and scan mirror side, EV radiance retrievals can be calculated by:

$$L_{EV} = \frac{1}{RVS_{EV}}[a_0 + b_1 dn_{EV} + a_2 dn_{EV}^2 - (RVS_{SV} - RVS_{EV})L_{SM}], \quad (4)$$

where RVS_{EV} is the EV RVS as a function of mirror incident angle. The TEB RVS comes from pre-launch tests for Aqua MODIS and from post-launch using pitch maneuvers for Terra MODIS. A detailed description on the MODIS TEB calibration is described by Xiong et al[14].

2.2 MODIS TEB electronic crosstalk

Signal contamination in the form of electronic crosstalk has been observed in many of the TEB since pre-launch. This became particularly evident for Terra MODIS bands 27 − 30 after the instrument experienced a safe mode event in February 2016, for which a correction was applied in C6.1 shortly after[10-13]. Moreover, some of the detectors in the Terra MODIS MWIR bands also show signs of electronic crosstalk contamination, which can be seen clearly from the Moon observations. Generally, crosstalk occurs between bands and detectors that are located on the same FPA. The source of the contaminating signals can be identified using lunar data. There are two kinds of crosstalk. One is detector 1 contamination from detector 10 of a sending band, as shown in Figure 1. This contamination is based on electronics sampling order, with the preceding detector contaminated by the following detector when the sampling switches between bands. The second is band-to-band among MWIR bands or among the photovoltaic (PV) LWIR bands.

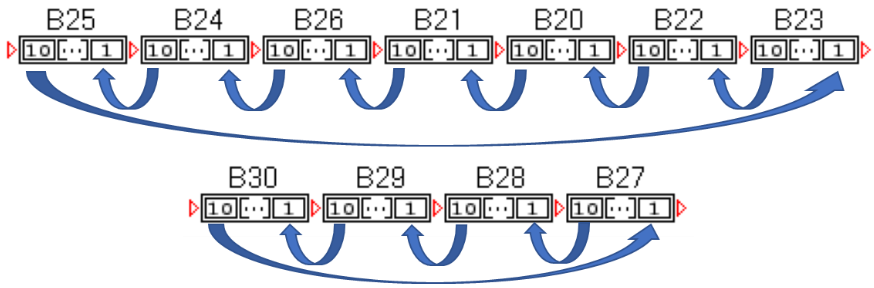

Figure 1. Illustration of detector 1 electronic crosstalk for both the Terra and Aqua MODIS TEB.

The contaminating signal is assumed to be proportional to the measured signal from the identified sending bands and affects the digital signal in each data sector. It has an impact on both the measured EV scene and on-board calibrator (OBC) data. In a simplistic fashion, the crosstalk coefficients, $c_{i,j}$, are in the form of a matrix which contains linear coefficient values that connect a detector's receiving contamination (*i)*, to each of the detectors that send contamination (*j*). Eq. 5 below describes the contamination

$$dn_i^*(S,F) = dn_i(S,F) + \sum_j c_{i,j} dn_j^*(S, F + \Delta F_j) \qquad (5)$$

Here, *S* and *F* represent the scan and frame numbers, respectively, ΔF_j is the relative frame offset of detector *j* with respect to detector *i*. *dn* is the background-subtracted digital counts for each data sector without crosstalk, and the * represents the digital counts with contamination. This equation is used for regression for the crosstalk coefficients from lunar measurements. A detailed description of the correction and its impact on the L1B data is described by Wilson et al.[11], and in the 2018 MODIS TEB electronic crosstalk workshop[15].

2.3 MODIS TEB C7 calibration algorithm

The MODIS C7 LUT on-orbit algorithm updates for the Terra and Aqua MODIS TEB are summarized in Tables 2 and 3. The C6.1 calibration algorithms are listed for comparison. The band 21 calibration algorithm is the same for C6.1 and C7; where the b_1 linear coefficient (not described in the Tables) being derived using the on-board BB cooldown (CD) data - with the offset and non-linear calibration terms constrained to zero in the fitting algorithm. The Terra MODIS photoconductive (PC) LWIR TEB crosstalk coefficients were derived using lunar observation analyses from mission beginning, and the crosstalk corrections have been applied to C6.1. There are three major C7 improvements:

1) Crosstalk corrections for select detectors in the MWIR bands are applied to both Terra and Aqua MODIS.
2) PV LWIR bands crosstalk corrections are applied to Aqua MODIS.
3) Calibration offset corrections are applied to select bands for Terra and Aqua MODIS, including the Terra PC bands during early mission.

It is also important to mention that the algorithm used to estimate the uncertainty associated with the electronic crosstalk has been improved for the Terra PV LWIR bands and added to Aqua PV LWIR bands, as well as the select detectors in the MWIR bands for both Terra and Aqua MODIS. Aqua MODIS had a safe mode March 2022. Due to the crosstalk contamination increase after safe mode, the correction for PV LWIR bands crosstalk is applied. In this paper, we present the C7 crosstalk correction and its associated uncertainty.

Table 2. Terra MODIS C6.1 and C7 TEB calibration algorithms. (PL: pre-launch; CD: cooldown)

<table>
<tr><th rowspan="2">Band</th><th colspan="2">Terra C6.1</th><th colspan="2">Terra C7</th></tr>
<tr><th>Calibration algorithm</th><th>Crosstalk correction (for calibration and EV)</th><th>Calibration algorithm</th><th>Crosstalk correction (for calibration and EV)</th></tr>
<tr><td>20</td><td rowspan="9">$a_{0\_ms1} = 0$
$a_{0\_ms2} = a_{0\_ms2}^{free\text{-}fit} - a_{0\_ms1}^{free\text{-}fit}$
CD a_2</td><td rowspan="5"></td><td>Corrected a_0; CD a_2</td><td rowspan="5">Electronic cross-talk corrections for selected detectors</td></tr>
<tr><td>22</td><td rowspan="6">$a_{0\_ms1} = 0$
$a_{0\_ms2} = a_{0\_ms2}^{free\text{-}fit} - a_{0\_ms1}^{free\text{-}fit}$
CD a_2</td></tr>
<tr><td>23</td></tr>
<tr><td>24</td></tr>
<tr><td>25</td></tr>
<tr><td>27</td><td rowspan="4">PV LWIR electronic cross-talk</td><td rowspan="4">PV LWIR electronic cross-talk</td></tr>
<tr><td>28</td></tr>
<tr><td>29</td><td>Corrected a_0; CD a_2</td></tr>
<tr><td>30</td><td>MS Corrected a_0
CD a_2 ; Fixed after 2003</td></tr>
<tr><td>31</td><td rowspan="6">$a_0 = 0$
CD a_2</td><td></td><td rowspan="2">a_0 =0
CD a_2</td><td></td></tr>
<tr><td>32</td><td rowspan="5">PC LWIR optical cross-talk</td><td rowspan="5">PC LWIR optical cross-talk</td></tr>
<tr><td>33</td><td rowspan="4">Early mission:
MS corrected a_0
Since 2003: a_0 =0
CD a_2</td></tr>
<tr><td>34</td></tr>
<tr><td>35</td></tr>
<tr><td>36</td></tr>
</table>

Table 3. Aqua MODIS C6.1 and C7 TEB calibration algorithms.

<table>
<tr><th rowspan="2">Band</th><th>Aqua C6.1</th><th colspan="2">Aqua C7</th></tr>
<tr><th>Calibration algorithm</th><th>Calibration algorithm</th><th>Crosstalk correction (for calibration and EV)</th></tr>
<tr><td>20
22-25</td><td rowspan="5">PL a_0
PL adjusted
CD a_2
(CD: cooldown).</td><td>PL a_0 with MS correction
CD a_2</td><td>Crosstalk corrections for selected detectors</td></tr>
<tr><td>27</td><td rowspan="2">PL a_0 with MS correction, CD a_2
No a_2 change after 2012036</td><td>Crosstalk corrections for all detectors</td></tr>
<tr><td>28</td><td></td></tr>
<tr><td>29</td><td>PL a_0 with MS correction and Dome-C based correction,
CD a_2 No a_2 change after 2012036</td><td rowspan="2">Crosstalk corrections for all detectors</td></tr>
<tr><td>30</td><td>PL a_0 with MS correction, CD a_2
No a_2 change after 2012036</td></tr>
<tr><td>31, 32</td><td>a_0=0, CD a_2</td><td rowspan="2">Entire mission MS corrected a_0
CD a_2</td><td rowspan="2"></td></tr>
<tr><td>33-36</td><td>a_0=0
PL adjusted CD a_2</td></tr>
</table>

3. MODIS TEB C7 CROSSTALK CORRECTION

3.1 MWIR electronic crosstalk

A crosstalk correction for select detectors in the MWIR bands is applied in C7 for both Terra and Aqua MODIS. Each detector that was selected for correction underwent extensive evaluation of the correction's impact on the L1B product and image quality. Four detectors (band 22 detector 8, band 23 detectors 1 and 10, and band 24 detector 1, Product Order (P.O.)) in the Terra MWIR bands and 5 detectors (detector 1 of bands 20, 22, 23, 24, and 25, P.O.) in the Aqua MWIR bands have contamination levels that are significant enough to require a correction in the L1B product. Figure 1 shows the crosstalk coefficient trending of Terra MODIS band 23 detector 1 and band 24 detector 1. Over the entire mission, the Terra MODIS MWIR bands crosstalk has decreased gradually, and the 2016 safe mode event did not have significant impact. Among the MWIR bands, band 24 detector 1 has the largest contamination. The sending signal is from band 26 detector 10. During daytime, band 26 (a short wavelength IR and reflective solar band) can have high signals, and the contrast with band 24 can be large, especially for low brightness temperature (BT) scenes, such as clouds and ice. The crosstalk effect on the BB calibration measurements is small, since band 26 has low signal from the BB view.

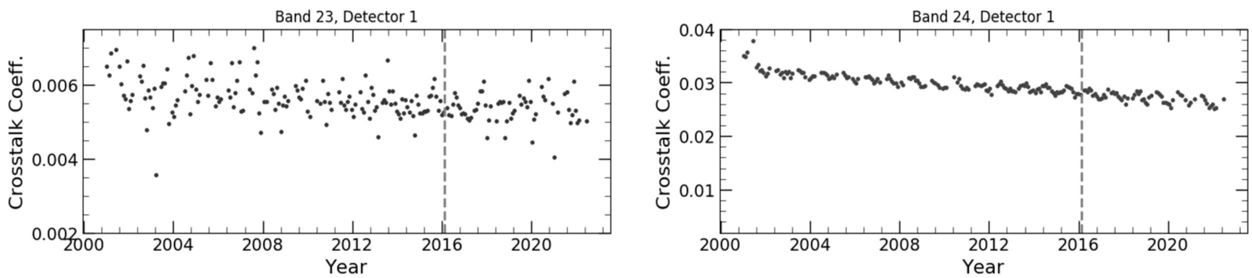

Figure 1. Terra MODIS C7 MWIR electronic crosstalk correction coefficients mission-long trends for detector 1 of bands 23 and 24 (detector in product order). The vertical dashed line indicates the time of the 2016 safe mode event.

Figure 2 shows examples for the Aqua MWIR bands crosstalk coefficients trending over the mission. Similar to the Terra MWIR bands, the crosstalk has a slight downward trend over the entire mission. Band 24 detector 1 has an approximately 4% crosstalk coefficient signal sending from band 26 detector 10. The contamination during daytime measurements has the largest impact, especially for low BT scenes. For both the Terra and Aqua MODIS MWIR bands, the crosstalk contamination on the selected detectors (mostly detector 1) cause striping in the L1B images. It is demonstrated that the correction generally reduces the striping.

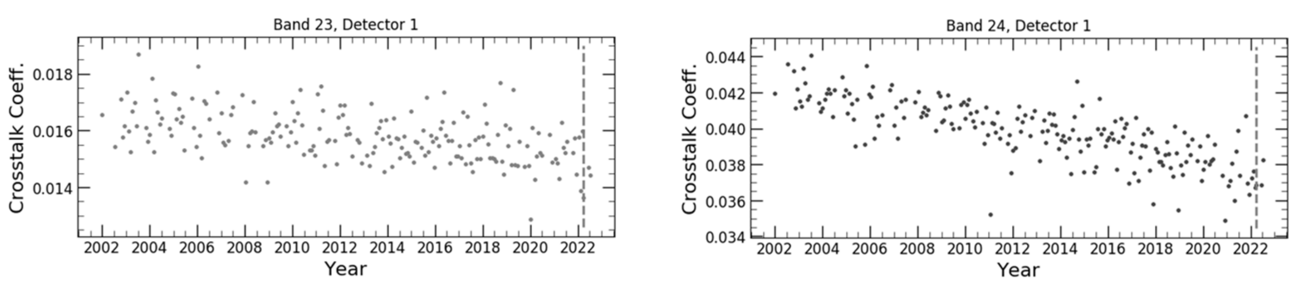

Figure 2. Aqua MODIS C7 MWIR electronic crosstalk correction coefficients mission-long trends for detector 1 of bands 23 and 24 (detector in product order). The vertical dashed line indicates the time of the 2022 safe mode event.

3.2 PV LWIR electronic crosstalk

The MODIS PV LWIR bands 27 to 30 crosstalk was identified during prelaunch testing and observed in orbit. The crosstalk coefficients can be derived from monthly lunar events and be assessed from Earth imagery. The Terra safe mode event in 2016 had a large impact on the crosstalk, as shown in Figure 3. The correction for the Terra PV LWIR bands crosstalk is applied in C6.1 and will also be applied in C7. The correction is applied to the BB WUCD calibration, scan-by-scan calibration, and EV L1B data. The correction greatly enhances the PV LWIR bands calibration accuracy and image quality.

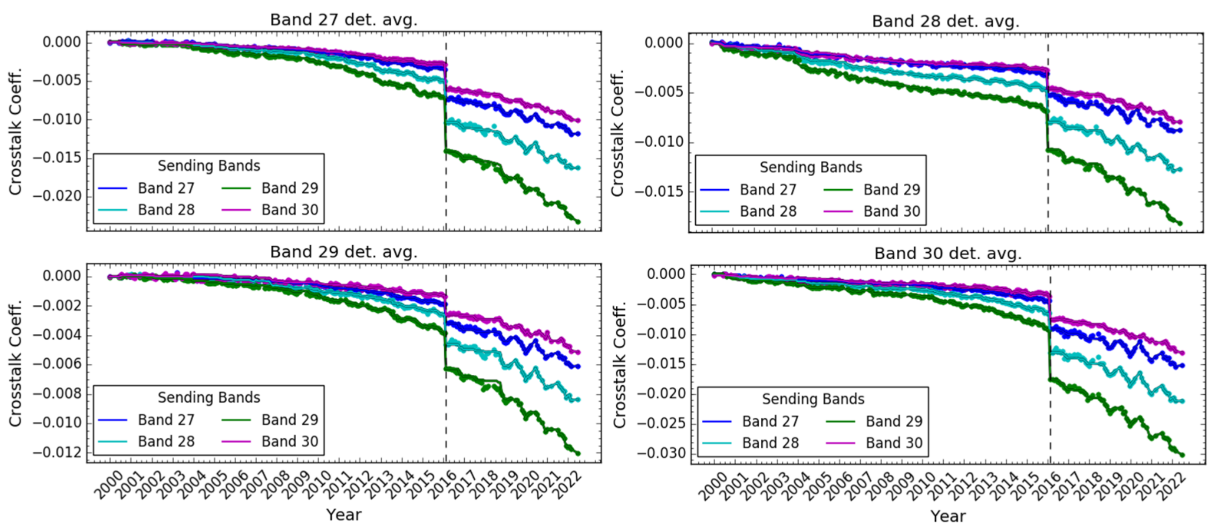

Figure 3. Terra MODIS PV LWIR bands electronic crosstalk correction coefficients mission-long trends. The coefficients are sending band and receiving band averaged. The vertical dashed line indicates the time of the 2016 safe mode event.

The Aqua PV LWIR bands have a similar issue as for Terra, albeit to a smaller degree of crosstalk contamination, so no correction was applied in the original C6.1 algorithm. A recent Aqua safe mode that happened on March 2022 caused an increase in the crosstalk contamination. As a result of the safe mode, crosstalk corrections began to be applied to the forward calibration of C6.1 LUTs post safe mode. They will be applied for the full mission in C7. Figure 4 shows the Aqua MODIS electronic crosstalk correction coefficients mission-long trends for bands 27 through 30. These crosstalk coefficients are derived from lunar observations. Bands 27 and 29 have similar trending patterns, while band 28 crosstalk is insignificant before the safe mode and increases after.

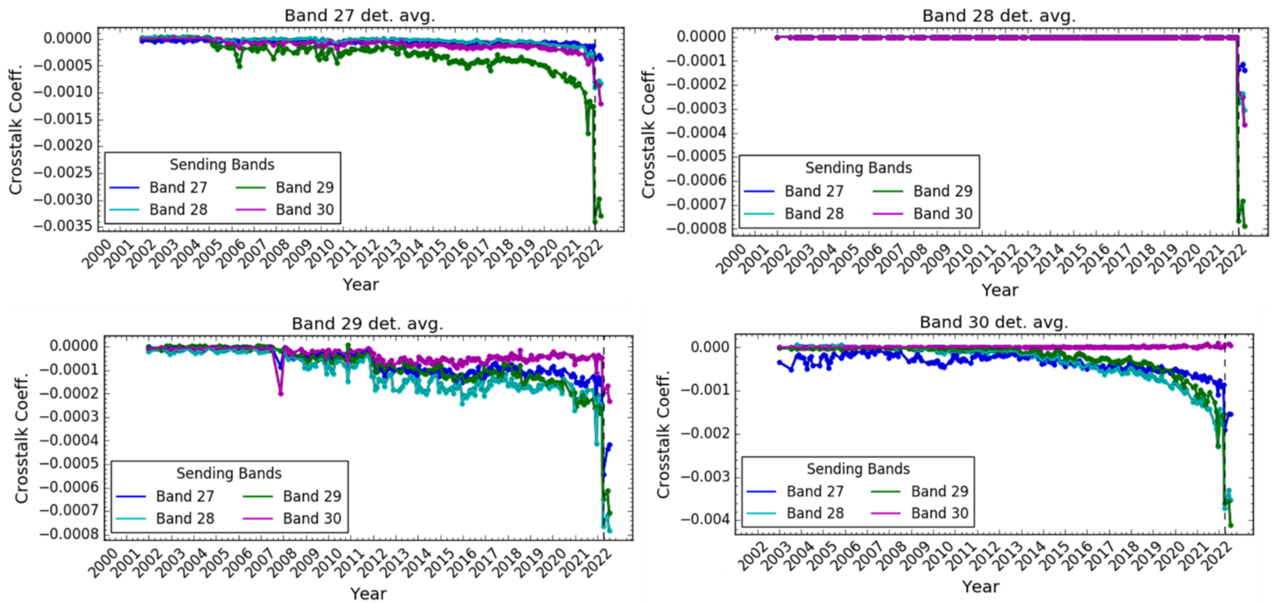

Figure 4. Aqua MODIS PV LWIR bands electronic crosstalk correction coefficients mission-long trends. The coefficients are sending band and receiving band averaged. The vertical dashed line indicates the time of 2022 safe mode event.

3.3 Earth L1B image assessments

The crosstalk contamination can be observed from the Earth L1B images. The image striping is due to individual out-of-family detectors due to the crosstalk. It can also apply to the case that the crosstalk contamination is very different amongst the detectors. Looking at the Earth image quality can be used for crosstalk correction assessments. We use the histogram over a scene and compare the histograms between detectors. Over large areas, it is expected that the retrievals of each detector within a band should be very similar. An out-of-family histogram indicates that the detector may be contaminated by crosstalk. Figure 5 shows the crosstalk correction assessment using an Earth image for Aqua band 24. The top images represent the true color image of the selected granule, and the image before and after the crosstalk correction. The bottom-left chart shows the histogram comparison for each detector before and after correction. The bottom-right chart shows a vertical BT profile before and after correction. Comparing the histograms, the correction brings the out-of-family detector back to family. For band 24, the detector 10 to detector 1 crosstalk causes large image striping, especially for low BT scenes, such as clouds and ice, as shown in the figure. After the correction, the striping is generally removed.

After the crosstalk correction was applied to the Aqua PV LWIR bands, Earth image assessments were performed. For the Aqua PV LWIR bands, the contamination is due to two kinds of crosstalk, as presented in Section 2.2. One is the detector 10 to detector 1 crosstalk, and the other is band-to-band crosstalk. The contaminations for each detector are different and cause striping in the Earth imagery. Figure 6 shows the crosstalk correction assessment using an Earth image for Aqua band 30. The top images represent the true color image of the selected granule, and the image before and after the crosstalk correction. The bottom-left chart shows the histogram comparison for each detector before and after correction. The bottom-right chart shows a vertical BT profile before and after correction. The striping is significantly reduced and the image quality is improved.

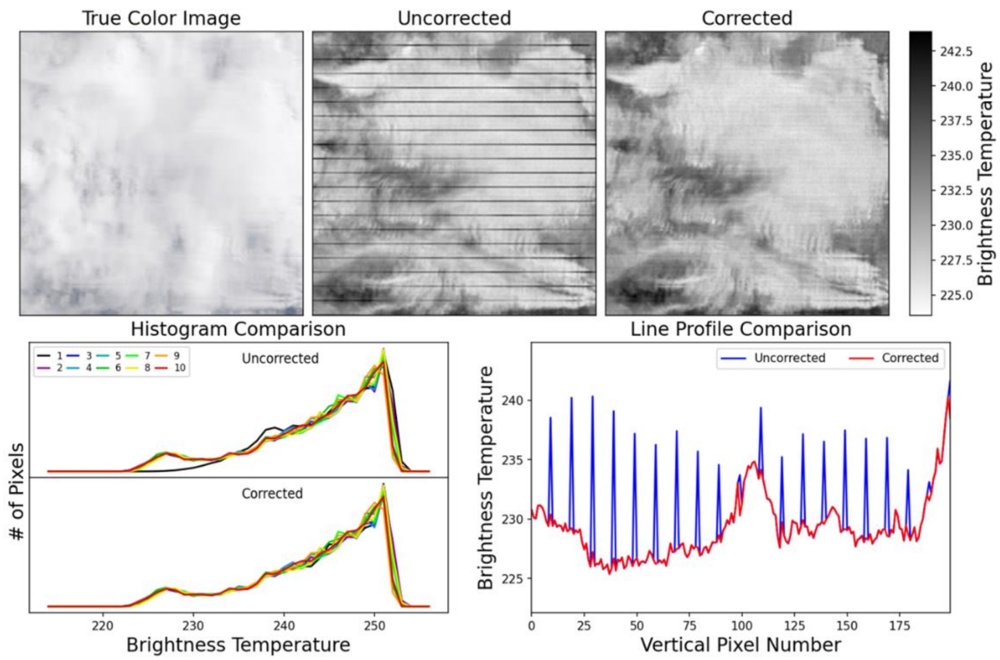

Figure 5. Crosstalk correction assessment using Earth imagery for Aqua band 24. The top images represent the true color image of the selected granule, and the image before and after the crosstalk correction. The bottom-left chart shows the histogram comparison for each detector before and after correction. The bottom-right chart shows a vertical BT profile before and after correction.

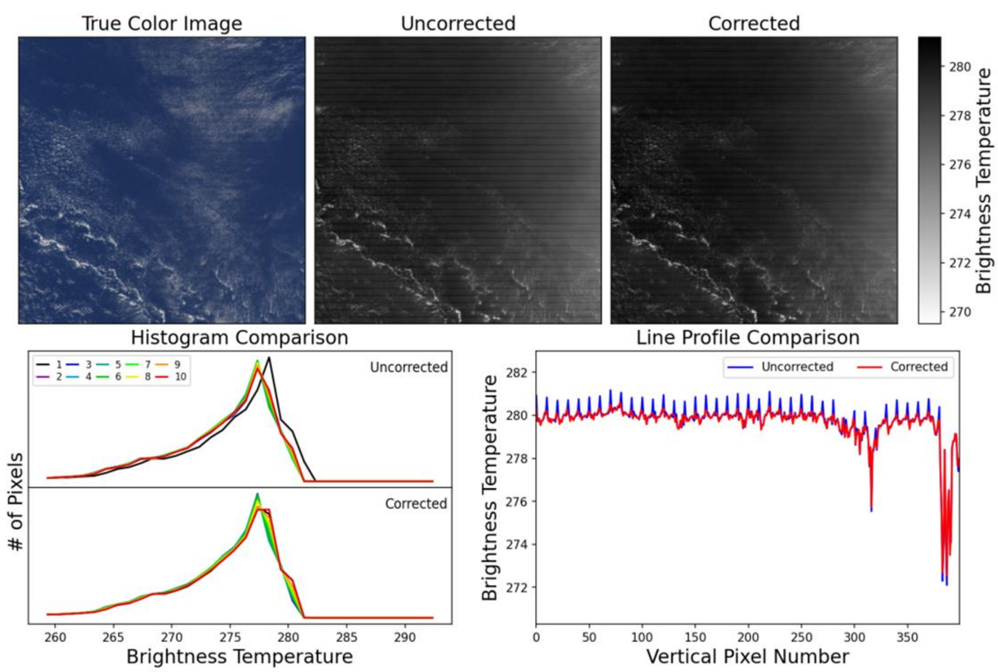

Figure 6. Crosstalk correction assessment using Earth imagery for Aqua band 30. The top images represent the true color image of the selected granule, and the image before and after the crosstalk correction. The bottom-

left chart shows the histogram comparison for each detector before and after correction. The bottom-right chart shows a vertical BT profile before and after correction.

4 C7 CROSSTALK UNCERTAINTY

The MODIS L1B products include the uncertainty at the pixel level. The crosstalk contamination adds uncertainty to the L1B product associated to the receiving bands and detectors. The derived crosstalk coefficients from monthly lunar events have uncertainty and fluctuate. The crosstalk coefficient uncertainty propagates to the radiance or BT calculation through the crosstalk correction. The MODIS L1B C6.1 calibration algorithm has included an electronic crosstalk correction for Terra bands 27-30. For C7, the crosstalk impact on the uncertainty for the select detectors in the MWIR bands and all detectors in the PV LWIR bands is estimated.

4.1 Crosstalk coefficient uncertainty

The contamination due to crosstalk contributes additional uncertainty. The uncertainty of the crosstalk coefficients and their fluctuation relative to the LUT value can propagate to the L1B product. For C6.1, a penalty coefficient is estimated using the long-term trending of the contaminated band and a LUT was delivered. For C7, the crosstalk coefficient uncertainty is derived from the fitting residuals between the measured values and a linear fit over a three-year sliding window. Figure 7 shows one example of the fit for the band 27 detector 1 crosstalk coefficients. For those detectors with crosstalk from multiple sending detectors, the uncertainty is estimated for each coefficient.

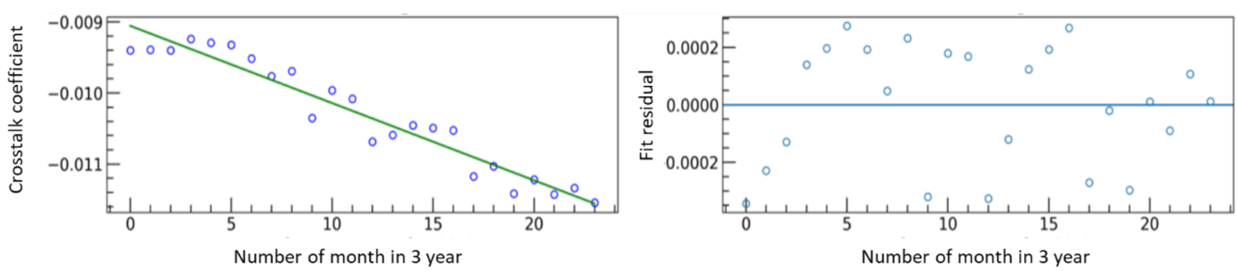

Figure 7. Crosstalk coefficient uncertainty estimation for Terra band 27 detector 1 (P.O.) from years 2019 to 2021. (Left) Linear fit of the crosstalk coefficients. (Right) The standard deviations of fitting residuals are used as the uncertainty of the crosstalk coefficients in this three-year time period.

The three-year sliding window is used to derive the crosstalk coefficients uncertainty over the mission. Figure 8 shows examples of the crosstalk coefficients uncertainties over the entire Terra mission. Terra had a safe mode event in 2016 that affected the crosstalk between the PV LWIR bands. The coefficients uncertainty after safe mode uses the three-year time period following the event. In Figure 8, there are flat lines for the uncertainty after safe mode. These crosstalk coefficient uncertainties are stored in a LUT that is used in the L1B product to estimate the total uncertainty using the uncertainty propagation formulation.

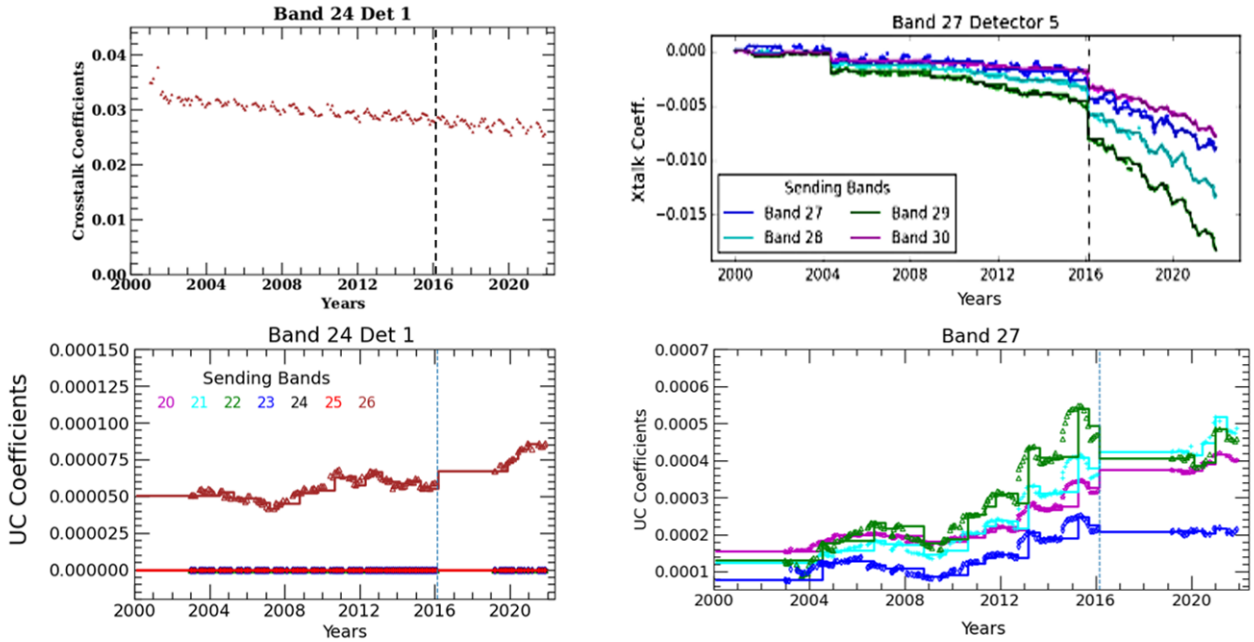

Figure 8. Terra MODIS crosstalk coefficients trending and derived uncertainties. The left figures are for band 24 detector 1 (P.O.) as an example for the MWIR bands, while the right figures are for band 27 detector 5 (P.O.) as an example for the PV LWIR bands. The horizontal lines are the LUT value. The vertical dashed line indicates the time of the 2016 safe mode event.

4.2 Uncertainty propagation and contribution to TEB uncertainty

The uncertainty of the crosstalk coefficients for each receiving detector propagates to the L1B data associated to this detector. A time-dependent uncertainty LUT is used for L1B processing. The uncertainty propagation for one receiving detector is the sum from all sending detectors. With the crosstalk coefficient uncertainty LUT, the uncertainty for a receiving detector due to the crosstalk is calculated as

$$unc = \frac{\sqrt{\sum_i (\Delta c_i * dn_i)^2}}{dn^*}, \tag{6}$$

where Δc is the crosstalk coefficient uncertainty from sending detector i, dn_i is the sending detector's digital number, and dn^* is the crosstalk corrected digital number of the receiving detector. The sum is over all sending detectors.

The uncertainty associated to crosstalk is scene and BT dependent. It is calculated for each pixel in L1B products. The uncertainty due to crosstalk is combined with the other uncertainty contributions for the TEB L1B data uncertainty estimation. Figure 9 shows bar charts for the MODIS TEB C7 uncertainty from years 2002 to 2021 for both Terra and Aqua MODIS. The uncertainty in this charts are offline analysis, and the pixel dependent uncertainties are not included. The red horizontal bars are the MODIS TEB uncertainty specifications. The uncertainty is not assessed for band 21, since this band is for fire detection and has a low radiometric calibration requirement. The Terra band 36 detectors are noisy, and the uncertainty is larger than the specification from mission beginning. The other bands meet the specification.

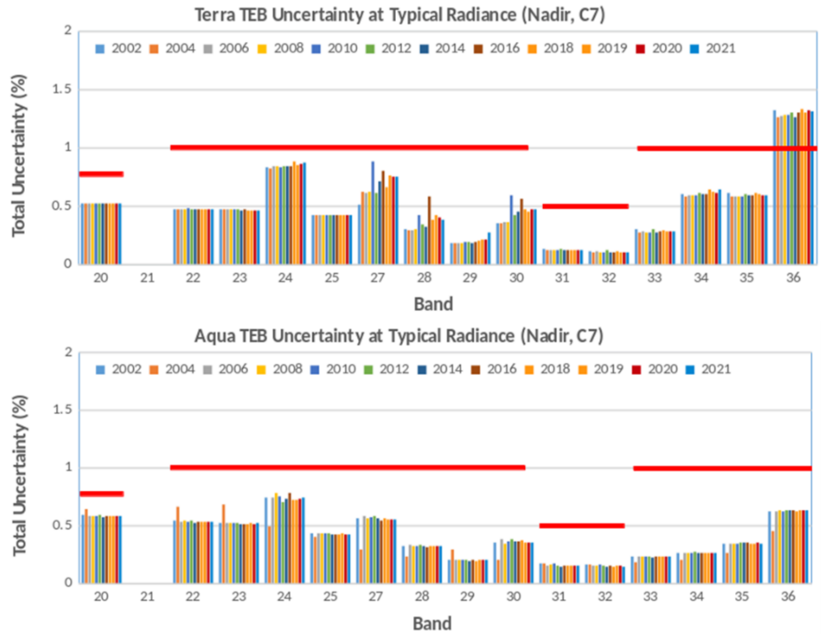

Figure 9. The MODIS TEB C7 uncertainty from years 2002 to 2021. The top chart is for Terra MODIS and the bottom is for Aqua MODIS.

5. SUMMARY

After more than 22 and 20 years in orbit, the Terra and Aqua MODIS TEB performance has been generally stable and the instruments continue to provide good quality L1B data. The Earth measurement assessments show that the major instrument configuration changes affect the instrument nonlinear response and crosstalk. The electronic crosstalk contamination affects the L1B image quality and calibration accuracy for the MWIR bands and PV LWIR bands. The C7 calibration algorithm improvements are based on a thorough review of the C6.1 TEB LUT algorithm, and calibration assessments using Earth scenes and sensor inter-comparisons. In addition to the correction for the Terra PV LWIR bands crosstalk in C6.1, crosstalk corrections for select detectors in the Terra and Aqua MWIR bands as well as all detectors in the Aqua PV LWIR bands are implemented in C7. This paper presents the crosstalk coefficients trending and the correction assessments using Earth imagery. The uncertainty associated with the crosstalk is also presented. With the C7 implementation of the calibration algorithm changes, improvements in image quality, measurement stability, and consistency are expected

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